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(12) UK Patent Application (19) GB (11) 2 383 413 (13) A

(43) Date of A Publication 25.06.2003

(21) Application No 0130609.1

(22) Date of Filing 21.12.2001

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(51) INT CL[7]
B61K 9/10 , G01N 29/04

(52) UK CL (Edition V)
G1G GPCX G9X
U1S S1744

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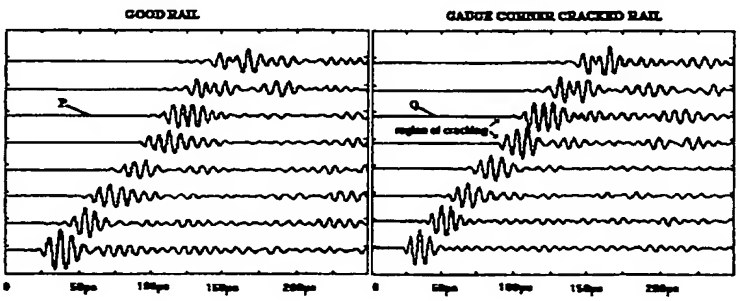
(58) Field of Search
UK CL (Edition V) G1G
INT CL[7] B61K, G01N
Other: ONLINE: WPI, JAPIO, EPODOC

(54) Abstract Title
Detecting rail defects using acoustic surface waves

(57) The system uses the velocity, attenuation, scattering, resonance and frequency absorbing properties of acoustic surface waves to detect defects in rails.

The apparatus (figs 12, 13) comprises a transmitter and a plurality of receivers of known types and is capable of performing real-time data acquisition. The method may be used to process and analyse real-time or pre-recorded data to determine the location, nature and probabilities of rail defects (fig 11).

FIG 3.,



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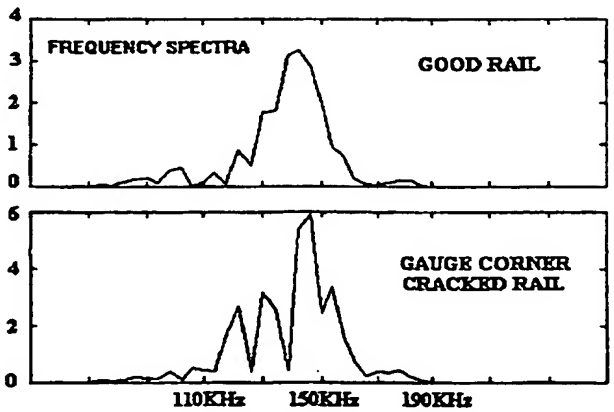

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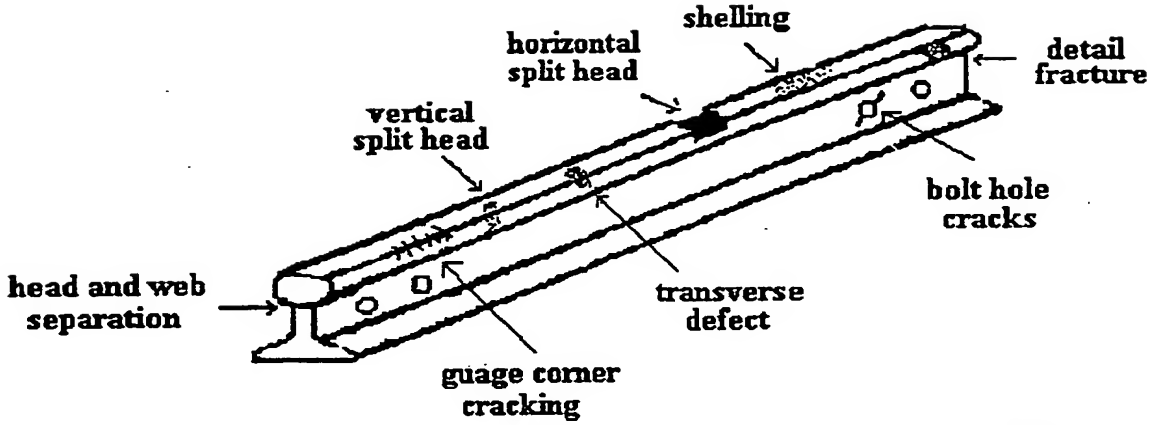
DRAWINGS

FIG 1.,



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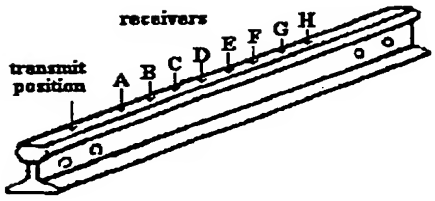

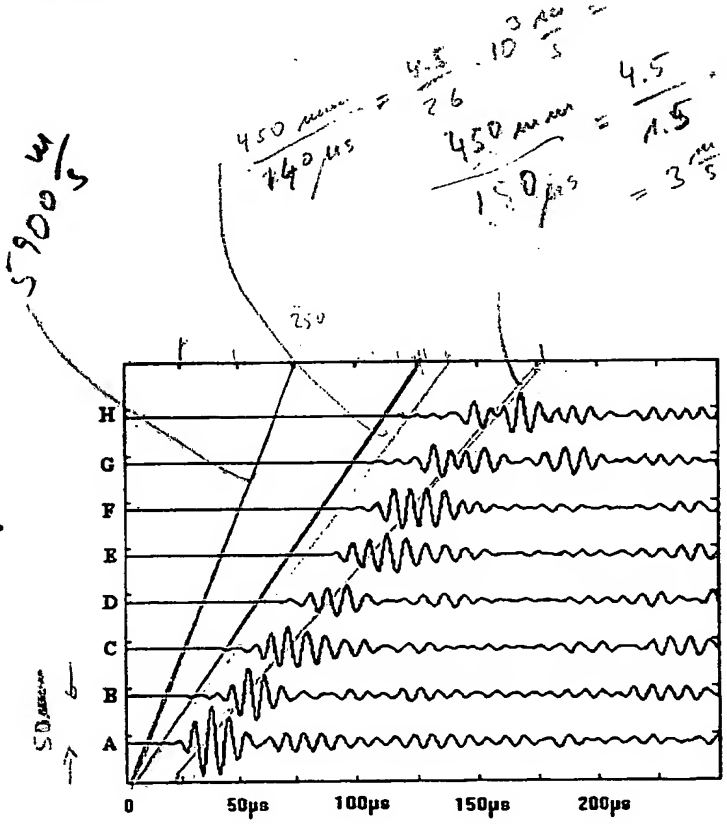

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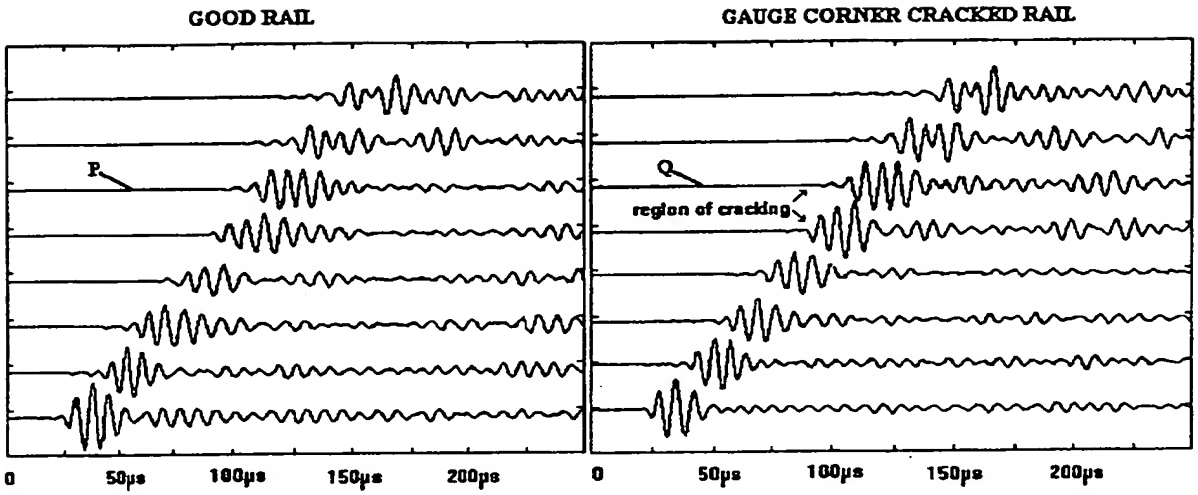
FIG 3.,



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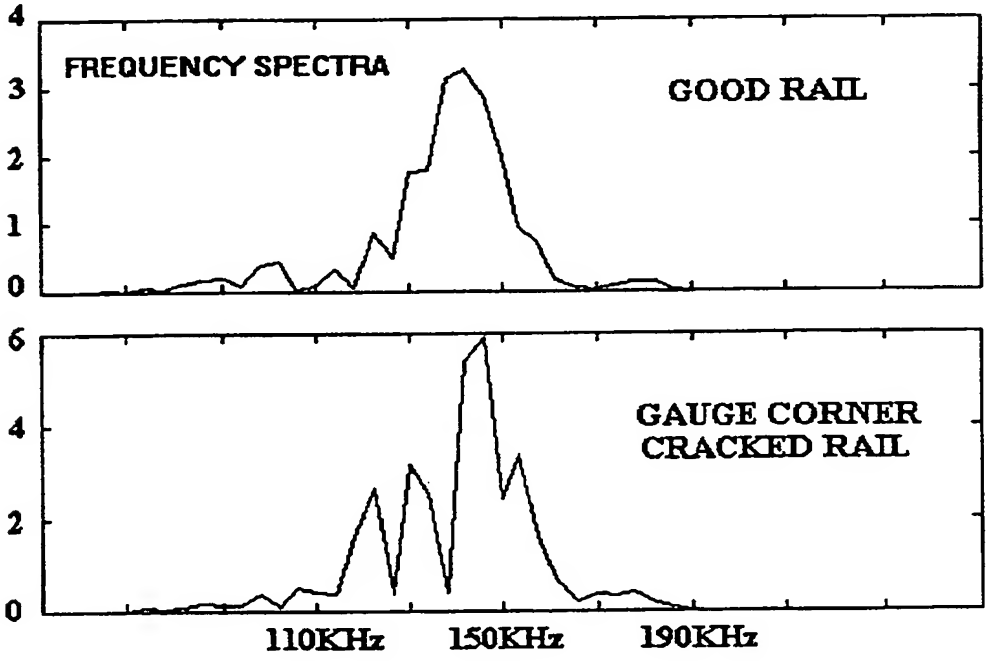

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FIG 5a.

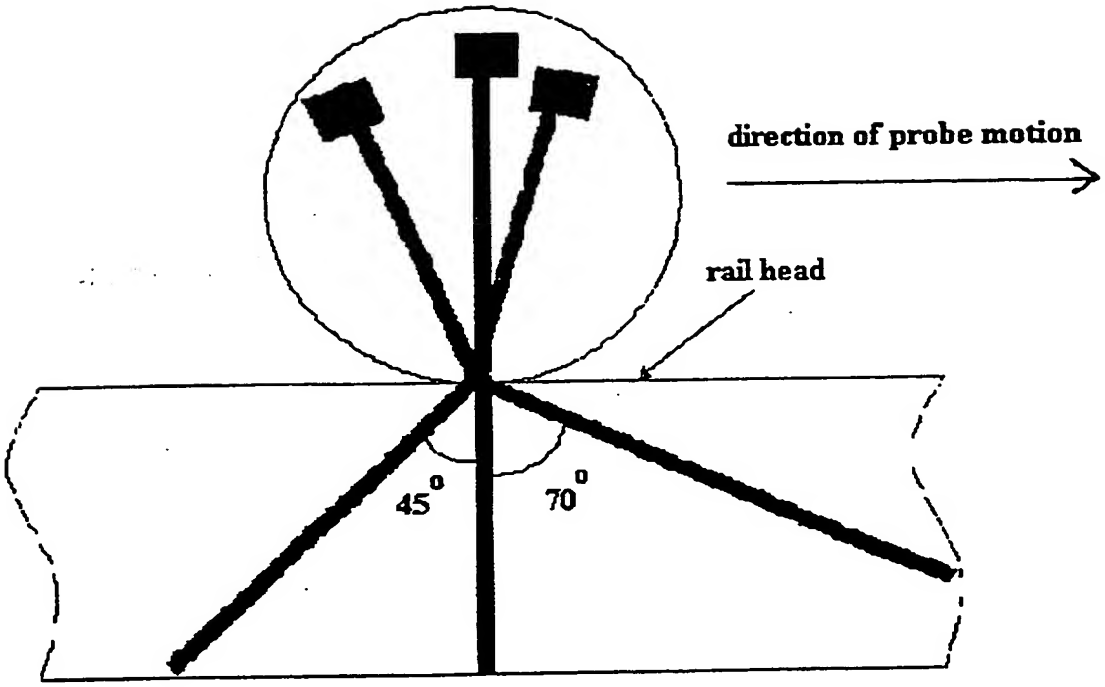
direction of probe motion
rail head
45°
70°

FIG 5b.

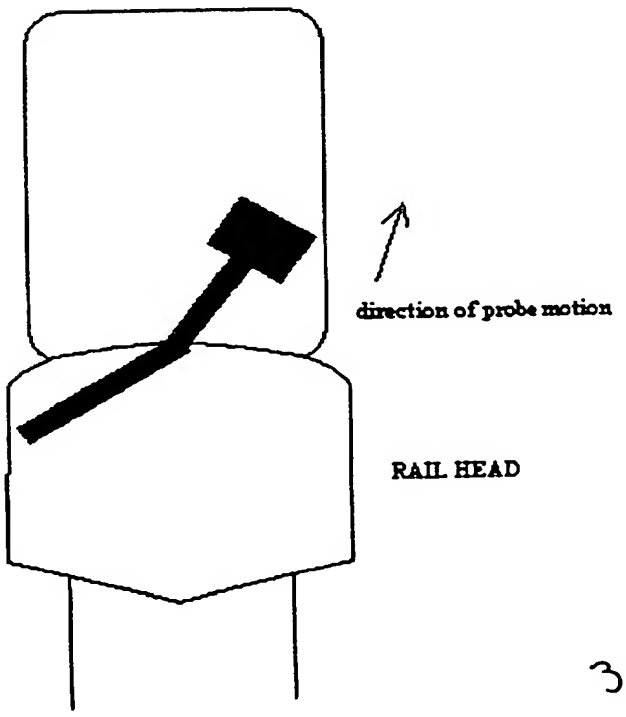
direction of probe motion
RAIL HEAD

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FIG 6a.

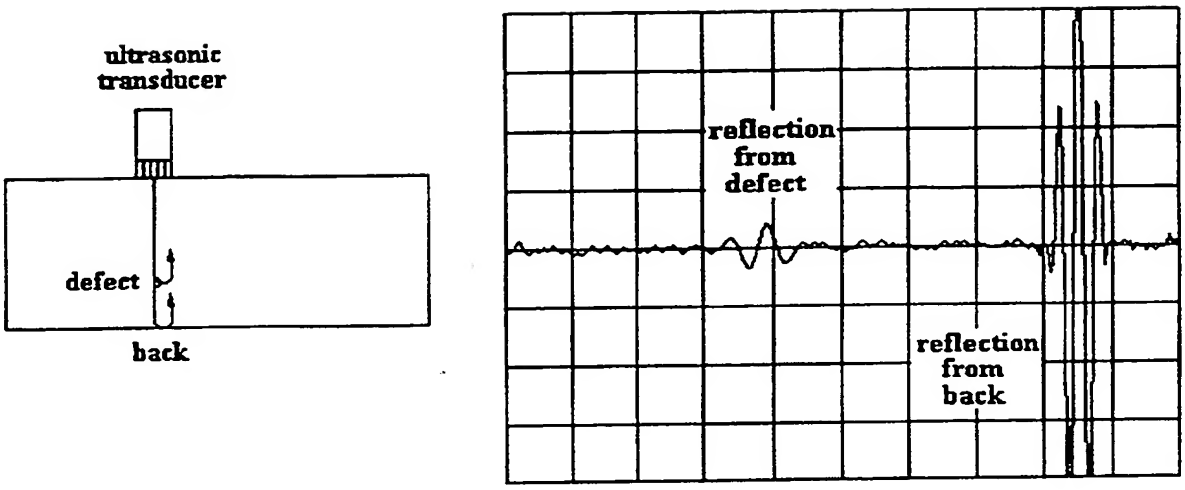
ultrasonic transducer
defect
back
reflection from defect
reflection from back

FIG 6b.

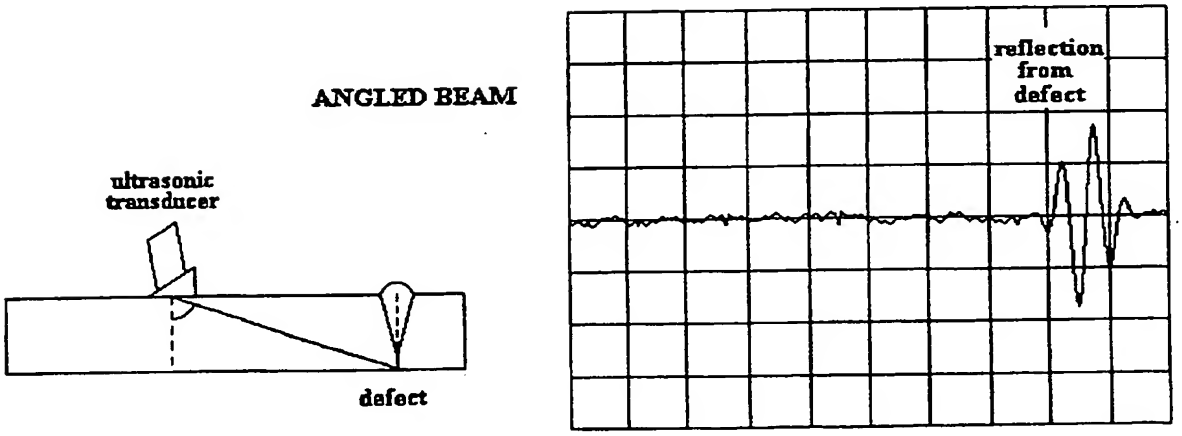
ANGLED BEAM
ultrasonic transducer
defect
reflection from defect

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FIG 7.

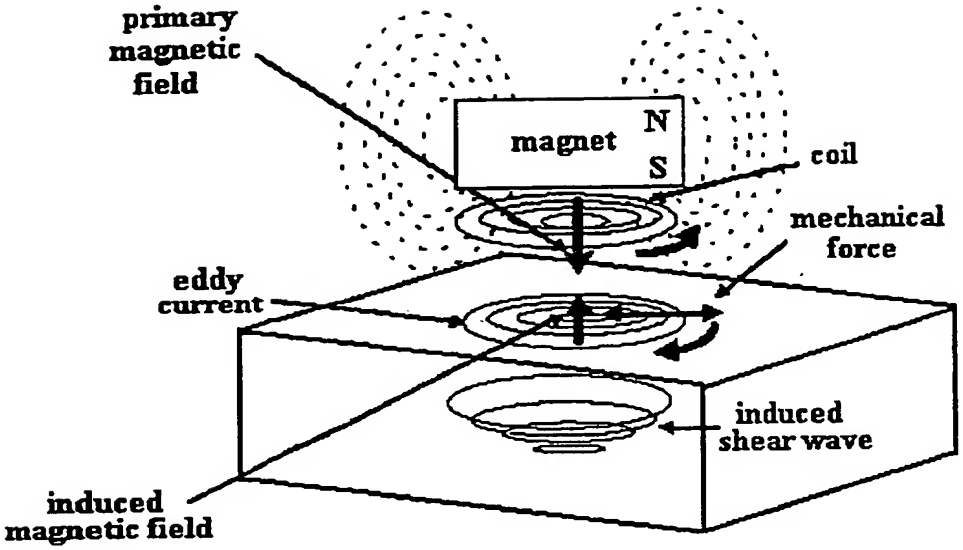

FIG 8.

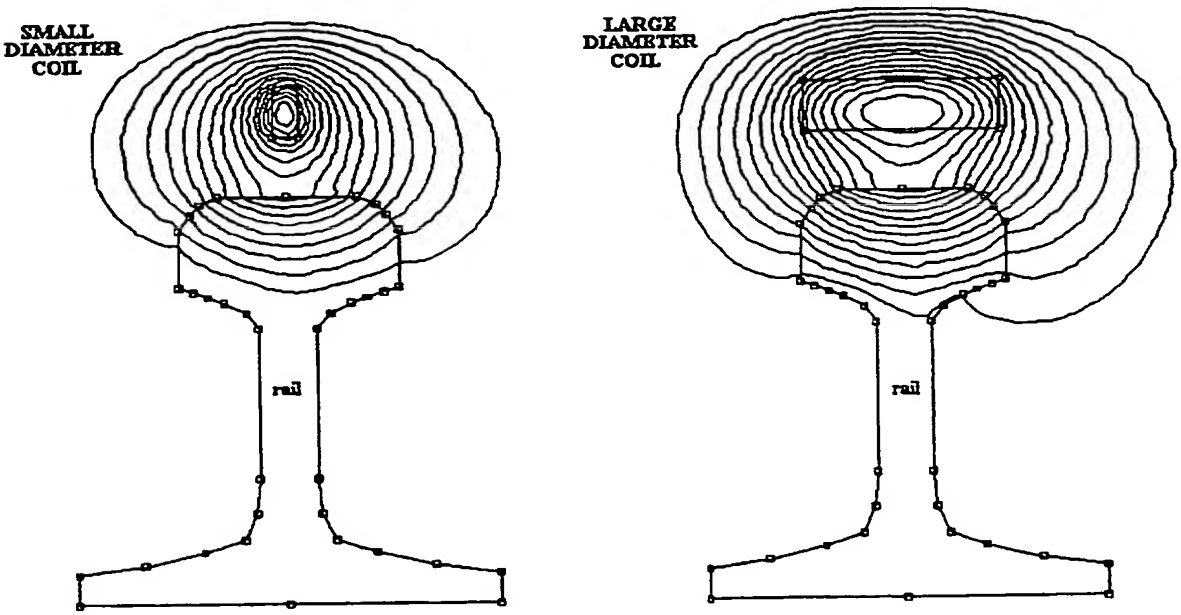

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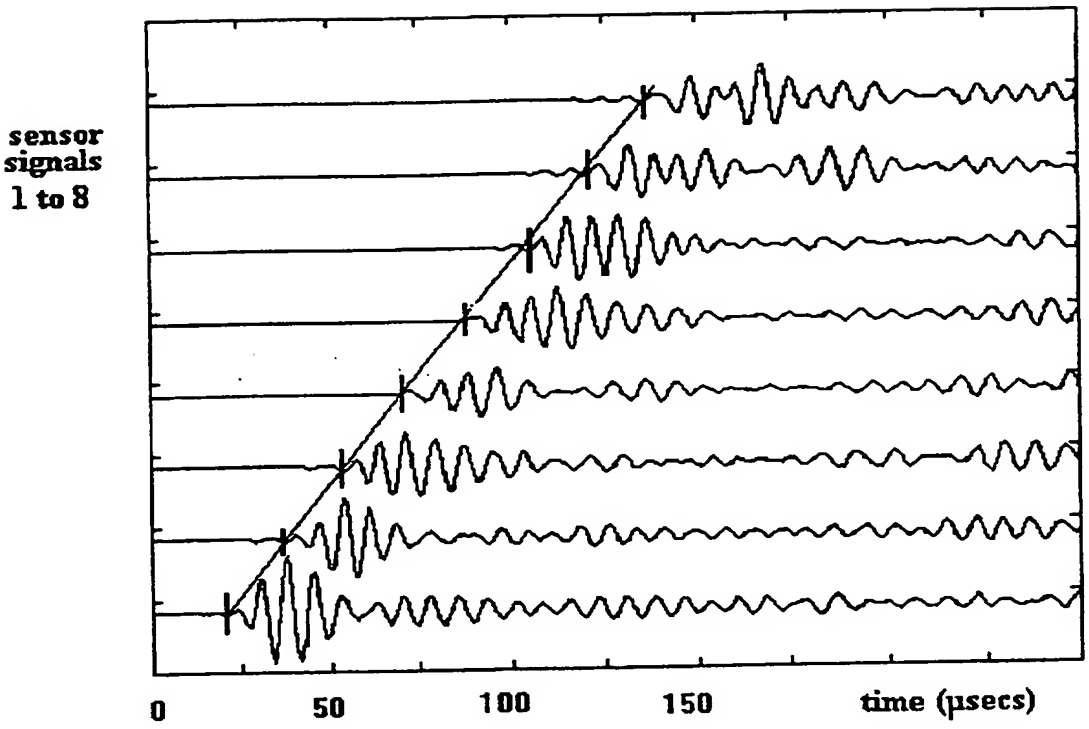
FIG 9.



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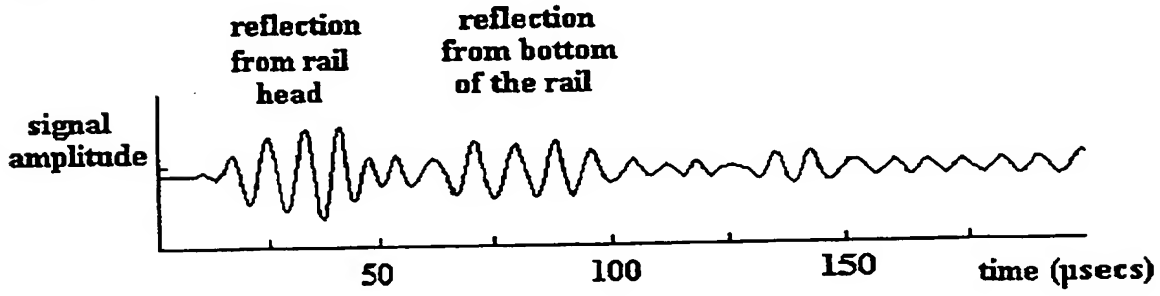

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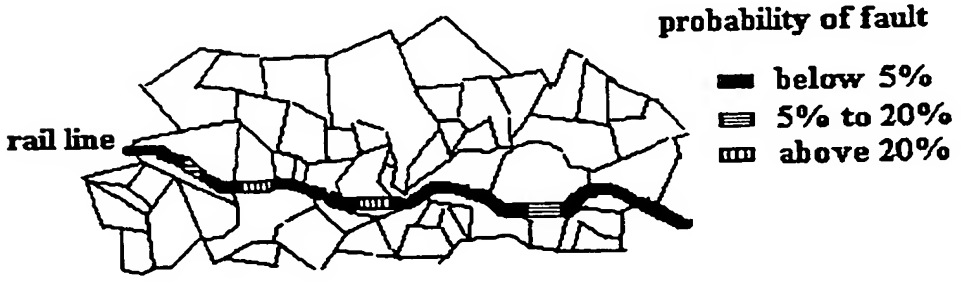

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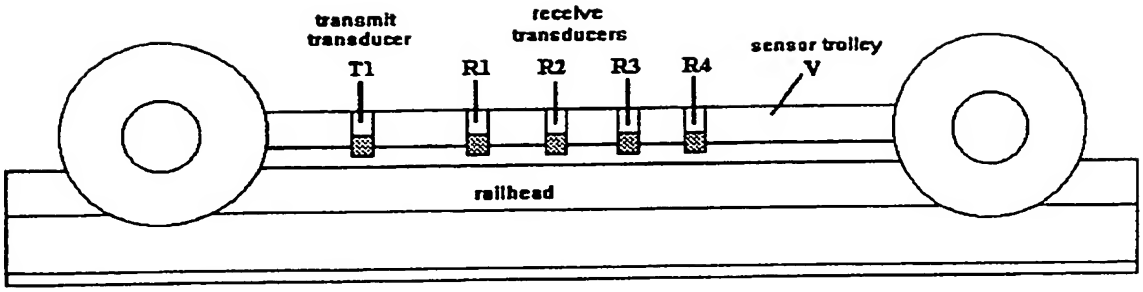
FIG 12.



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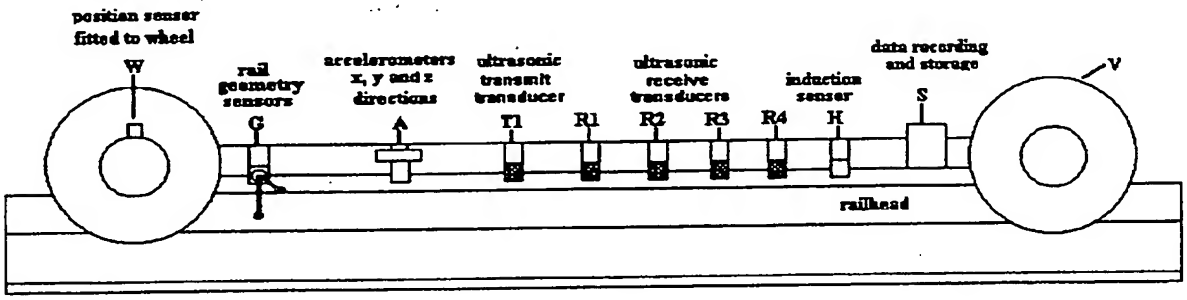

FIG 14.

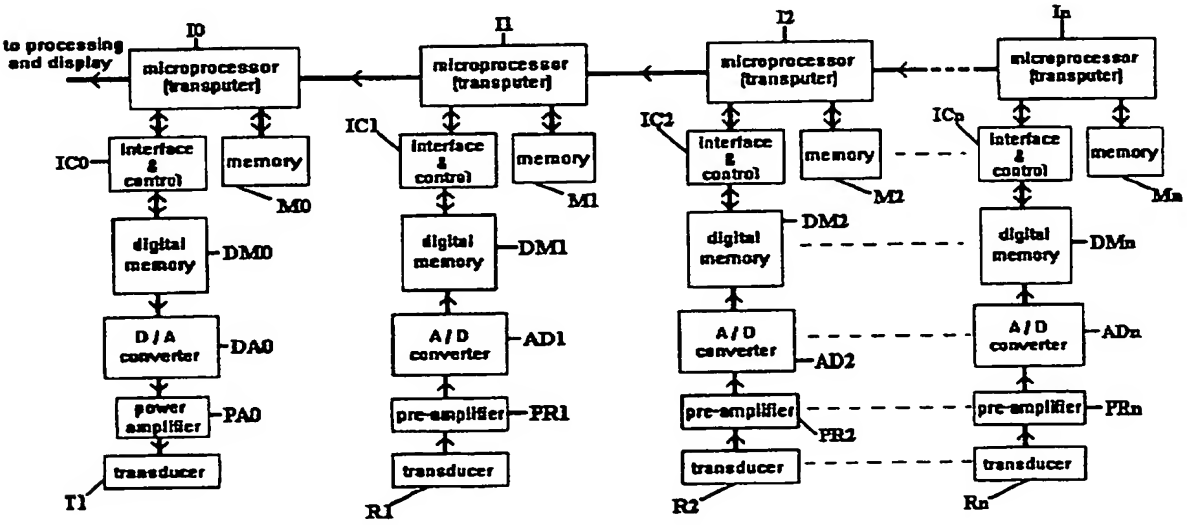

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FIG 15.

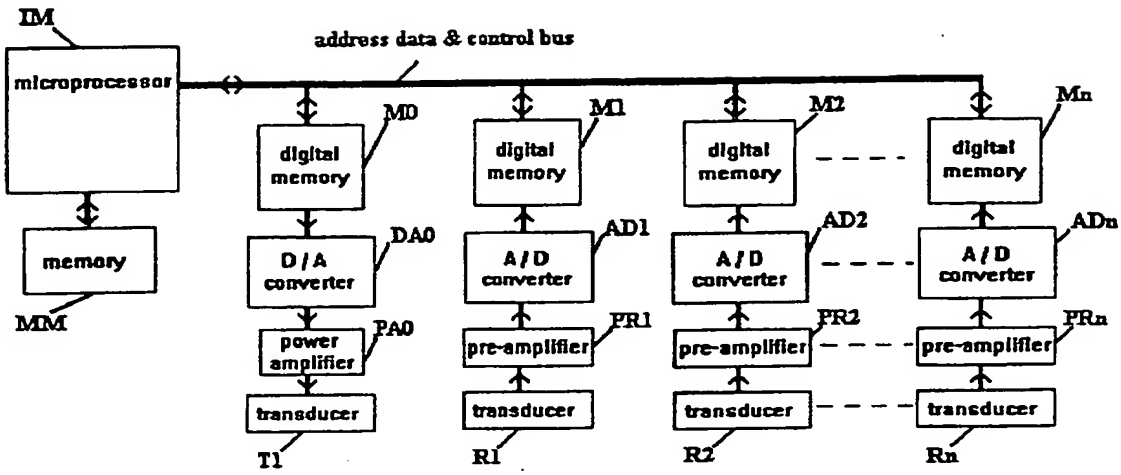

FIG 16.

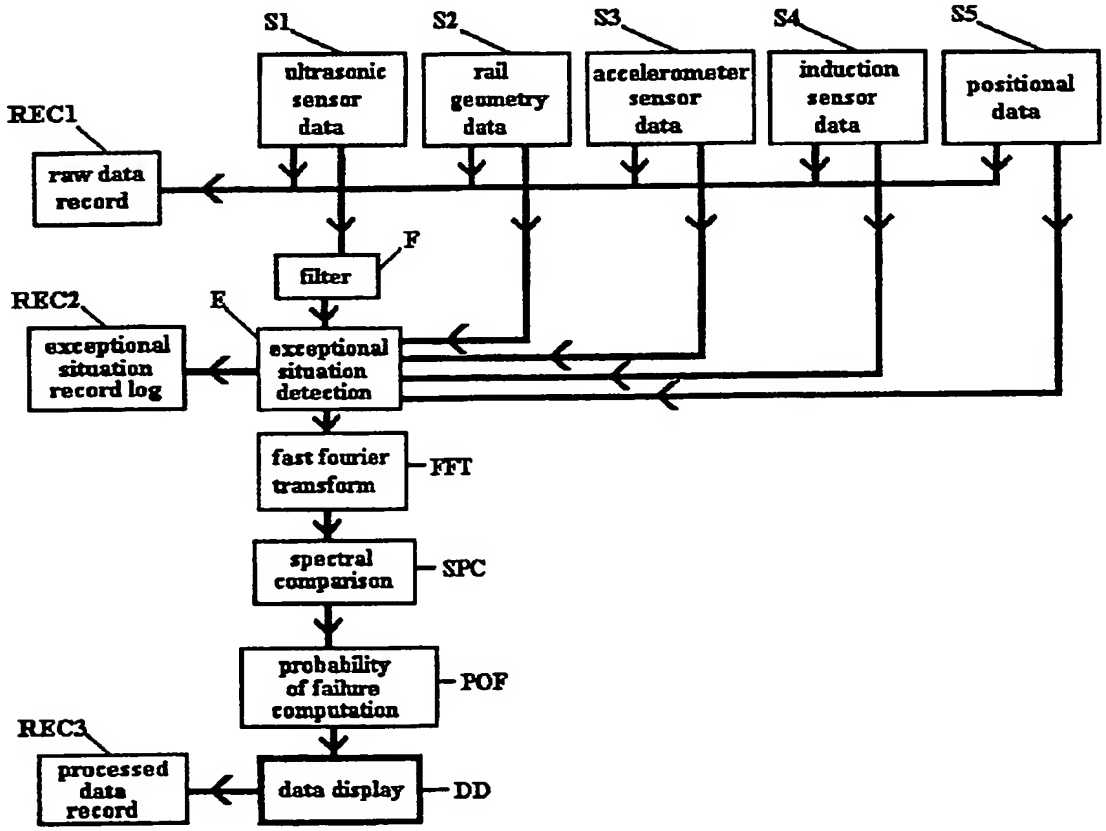

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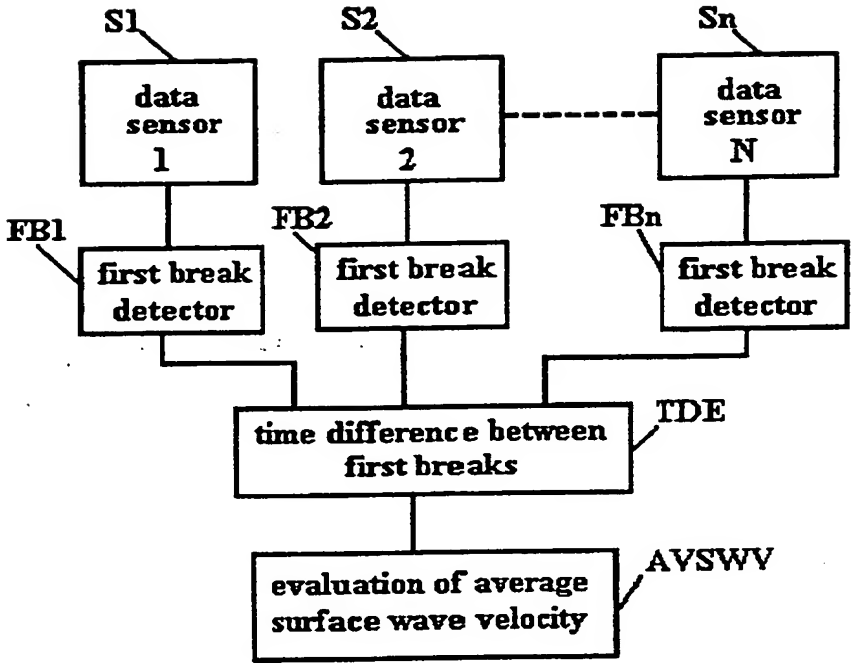
FIG 17.



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DESCRIPTION

BACKGROUND OF THE INVENTION

It is known that railway lines can develop a number of faults and defects during their manufacture or over their operational life time. Common faults that occur are head and web separation, vertical split head, horizontal split head, transverse defect, shelling, bolt hole cracking, detail fracture and gauge corner cracking.

In the UK before 1995/1996 an ultrasonic test unit (UTU) was used to inspect rail condition, running at speeds of about 40 mph. The unit produced a paper record of the ultrasonic reflection signals generated, also included were eddy current probes to supplement the ultrasonic detection, these were both analogue systems.
The system was withdrawn in 1996 due to the high number of false readings.

Since 1995/1996 non automatic methods are used in the testing of rails. Small hand held probes are used for detailed work, or trolleys equipped with an oscilloscope pushed by hand over the track for general surveys. These use 0 and 70 degree ultrasonic test probes.
This procedure limits inspection speeds to walking pace (about 4 mph).
The trolley does not provide a record of the track tested, it relies on the operator to ascertain the degree of defect and make a note of its location.
The trolley contains only two probes, they both run along the rail centre; therefore off axis defects are difficult to detect (such as gage corner cracking).

The rail industry in the UK is soon to re-introduce automatic testing and digital recording of data, with the inclusion of more ultrasonic sensor probes, eddy current probes and track geometry sensors.

Other countries already have advanced ultrasonic testing methods. The ultrasonic transducers are placed in a fluid filled wheel, the sound wave pulse is transmitted and received at various angles to the railhead. Sometimes a sliding plate instead of a wheel is used, the transducers fixed to this plate and water coupling applied as it is moved over the railhead.
High frequency ultrasonic sound waves are used, typically 1 to 2 MHz, giving high resolutions of the defects, typically a few millimetres. At present the reflection method is almost exclusively used in practical testing equipment.

Variations of the ultrasonic reflection method have been investigated, such as the use of guided longitudinal waves. In this method high frequency sound waves are transmitted along the railhead, using a magnetostrictive or piezoelectric transducer. The wave propagate longitudinally in the rail and are reflected back if they strike a transverse anomaly.
Other researchers have examined the use of Rayleigh (surface) waves, or Sezawa waves (second order Rayleigh waves) to detect surface and near surface defects. This method uses a process called the pitch-catch (or transmission) method. Two high frequency ultrasonic transducers (1 to 2 MHz) are used, one to transmit the sound pulse, the other at a short distance (typically 250mm) to receive it . By examining the attenuation of the surface sound wave as it travels over this short distance the presence of defects can be detected. The defects, in particular surface or near surface

cracks, will cause the sound wave intensity to diminish. This method only uses attenuation and is restricted by using high frequencies, it can only detect large faults within one or two millimetres below the surface of the rail head.

Recent research carried out at Exeter University, UK has resulted in a new method and procedure to detect rail defects. It uses the principle of sending a guided sound wave along the railhead. Experiments to date have used a frequency of 140KHz, giving a wavelength in steel of 42mm (bulk wave), 36mm (rod wave) or 21mm (Rayleigh or surface wave). The primary interest is not to resolve in great detail individual cracks, but to characterise the sound wave at various points along the surface of the rail as it propagates within and along the rail head. By examining these acoustic properties the extent of defects within a section of rail can be determined. By using low frequency sound waves the surface (Rayleigh) wave will be influenced by material properties to a depth of many millimeters below the rail heads surface, since this is a function of the wavelength (or operating frequency).

A particular method investigated was the frequency absorption and resonance that occurs in the surface wave as it travels across surface and near surface cracks. This method was particularly successful in detecting gauge corner cracks.

SUMMARY OF THE INVENTION

In accordance with this invention, there is provided a vehicle which comprises a plurality of acoustic sensors.
One or more of these sensors is designated a transmitter and the remaining sensors designated as receivers.
Each of these sensors are connected to a computer and data from them is electronically stored, processed and displayed to an operator.

A particular advantage of this apparatus is that the operational capability of this invention can be extended by the inclusion of a plurality of other sensors incorporated into the vehicle. These sensors being used to measure other physical properties of the railway line, such as its geometry and induced magnetic field response. This information being used to give additional certainty about the presence of defects on or within the rail.

A particular processing function which the apparatus can perform is measurement of the resonance and absorption spectra of sound waves propagating just below or along the surface of the rail head.

A further process which the apparatus can perform is the determination of the longitudinal and surface (Rayleigh) wave velocity and attenuation.

BRIEF DESCRIPTION OF THE DRAWINGS

An embodiment of this invention will now be described by way of example only and with reference to the accompanying drawings in which:

FIG 1. Is a general schematic view of typical rail defects.

FIG 2. Is a schematic diagram illustrating the inventions sensor arrangement.

FIG 3. Is example of typical signals obtained from good and bad rail.

FIG 4. Is example of the frequency spectra obtained from good and bad rail.

FIGS 5a and 5b. Are diagrams illustrating the operation of a wheel probe detector.

FIGS 6a and 6b. Are diagrams illustrating the principle of ultrasonic reflection.

FIG 7. Is a schematic diagram illustrating the electro magnetic acoustic transducer.

FIG 8. Is an example of the analysis of magnetic fields from coils around rail lines.

FIG 9. Is a diagram illustrating the method of surface wave velocity determination.

FIG 10. Is an example of sound reflections from the base of a rail.

FIG 11. Is an example of the form in which data from the invention can be displayed.

FIG 12. Shows the basic mechanical arrangement of the inventions sensors.

FIG 13. Shows how the invention can be incorporated into a larger system.

FIG 14. Is a schematic illustrating the data acquisition process (option 1).

FIG 15. Is a schematic illustrating the data acquisition process (option 2).

FIG 16. Is a schematic illustrating the method of data processing.

FIG 17. Is a schematic illustrating the method to determine surface wave velocity.

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DESCRIPTION OF THE DRAWINGS

Referring to FIG 1, there is shown a general schematic of the types of defect that occur in railway lines. Transverse defects have an origination point in the centre of the fissure and they grow circular to the origination point. Vertical split heads usually originate from manufacturing anomalies.
Horizontal split head, detail fracture and shelling occur through excessive loading applied to the rail. These can be detected by examining the rails geometry.
Head and web separations are caused by excessive lateral loads or manufacturing faults. Bolt hole cracks are formed from excessive tensile forces at connections between rail sections. These types of defect are readily detected by ultrasonic scans acting in the vertical direction.
Gauge corner cracking may occur from rolling contact fatigue. Cracks form and propagate within the rail head at the gauge corner. This type of defect is often difficult to detect in their early stages but as recently demonstrated they can be detected by ultrasonic inspection of a surface (Rayleigh) wave.

Referring to FIG 2, there is shown an example of the positions of ultrasonic transducers over a railhead. The receiver positions being identified by the letters A to H. The transmit position indicated on the left. The spacing between the transducers being adjusted to suit the particular requirements of the survey.
A sound wave pulse or waveform is transmitted at the indicated location on the railhead's surface. The receivers (A to H) located at fixed intervals along the rail head detect the wave as it travels along the rail. The signals at each receiver are recorded and an example of these signals is given as a plot in the figure (amplitude verses time).

In this particular example a section of good rail was used with a spacing between the receivers of 50mm. The largest amplitude signals on each trace correspond to the surface (Rayleigh) wave.
From this plot the velocity of the Rayleigh wave is measured to be 3000 m/sec which is very close to the theoretically predicted value of 2976 m/sec.

This plot also shows the very weak primary wave (the first signal to arrive), which will be the longitudinal (compressional) wave. This is measured to be about 5100 m/sec, which corresponds closely to the theoretical rod wave velocity for steel of 5176 m/sec. (when the bulk wave velocity in steel is 5925 m/sec).
As the surface (Rayleigh) wave travels over the rail head the initial wave shape is "stretched" or disperses; this is because different frequency components travel at different velocities and also the different modes of wave motion interact at different points along its path. In the presence of defects, such as surface or near surface cracks, the wave form will undergo a change in the vicinity of these defects.

Referring to FIG 3, there is shown a comparison between the signals received from an example of good rail and one that has gauge corner cracking. The region of extensive cracking noted on the figure. At these regions the waveform has undergone a change. Comparing the traces marked P and Q it can be seen that the surface wave has undergone attenuation and scattering in the presence of these cracks. The trace Q shows "noise" after the main energy of the surface wave has passed, this is called

coda and results from sound scattering in the vicinity of the receive transducers. This coda can be used to identify certain properties of the cracks in the material that produces it.

Referring to FIG 4, there is shown the difference between the frequency spectra of the signals indicated as P and Q on FIG 3. The good rail spectra follows closely to that of the waveform transmitted into the railhead, this is approximately Gaussian centred about 140 KHz. The gauge corner cracked rail shows notches or missing components in its spectra. This is due to the cracks selectively absorbing certain frequencies within the band width of the transmitted signal.

If other waveform types were to be transmitted into the rail, for example a frequency sweep, which would produce a broad spectrum over a specific range and if broad band transducers are used, then these notches in the spectra over a greater range can be examined.

Referring to FIG 5a and 5b which show a schematic of existing acoustic transducers used in rail testing.

The ultrasonic transducers are placed in a fluid filled wheel, the sound wave pulse is transmitted and received at various angles to the railhead. Sometimes a sliding plate instead of a wheel is used, the transducers fixed to this plate and water coupling applied as it is moved over the railhead.

Different transducer angles are used to find different types of defects.

Four different orientations usually used 0, 45 and 70 deg from the vertical in the forward and back directions along the rail head, and a side transducer looking across the rail. To obtain good resolution of the defects high frequency sound wave are used typically 1 to 2 MHz. Giving wavelengths in steel of 6 to 3 mm respectively.

Referring to FIG 6a and 6b which shows a schematic and associated waveforms from existing ultrasonic rail testing techniques.

Referring to FIG 7 which shows a schematic and illustrates the principle operation of the Electro-Magnetic Acoustic Transducer (EMAT).

This is a non contact device capable of producing an acoustic wave within a conductive material, such as steel.

The permanent magnet provides a static magnetic field. The coil placed between the magnet and steel rail head has a voltage pulse applied to it. The current pulse flowing in the coil induces a current in the steel rail (an eddy current), because of the presence of the static magnetic field, this eddy current flowing in the steel produces a mechanical force which is conveyed to the steel in the form of an acoustic pulse.

The receiver works in a similar fashion, when a vibration moves through a block of steel in the presence of a magnetic field, an eddy current is produced, this current can then induce a current to flow in a nearby coil.

By suitable coil winding design different types of sound waves can be generated within the metal. For example Rayleigh surface waves, longitudinal (pressure) or shear (transverse) waves acting in a specific direction

When these devices are used at high frequency (1.5 to 2.5 MHz) with coil diameters between 20 and 30mm then the distance from the probe to the metal surface is usually in the order of 0.5 to 1 mm, to produce optimum results.

However with the technique of this invention, the working frequency is much lower (typically 100 to 200 KHz), and as a consequence larger coils can be used. The probe distance from the metals surface can then be extended to ranges above 10mm. This is shown in FIG 8. The magnetic fields generated by a larger coil diameter can extend to a greater depth and are of greater magnitude within the railhead.

Referring to FIG 9. This illustrates the principle by which the velocities of propagation for the wave are determined.
The figure shows typical data that will be found from an array of sensors. The first breaks (the point at which the amplitude starts to rise) for the surface wave are indicated on each trace as a small vertical line. Some traces show a first break before this, which corresponds to the longitudinal compressional wave moving at a velocity of 5100 m/sec. This can be blanked out, or level adjusted, should we only require surface wave information. The amplitude of these compressional waves are very much lower than that of the surface wave.
The velocity of the surface wave is found by finding the gradient of the line passing through these first breaks, and knowing the distance between each sensor.

Referring to FIG 10. This shows an example of a typical waveform received when the transmit and receive sensors are in very close proximity to the surface of the railhead, and with the sound wave directed down into the rail.
Examination by this method known and is used to detect rail head separations from the web, it involves the detection of a reflection from the base of the rail. Existing techniques use high frequency ultrasonic pulses. The apparatus of this invention uses lower frequency sound waves and as a consequence the resolution will be low.
The rail base reflection will be present but it may overlap with the reflections from those from the rail head section. Detecting the absence of a signal after 50 microseconds will indicate that the head has separated from the web section.

Referring to FIG 11. This shows an example of a method by this apparatus displays rail faults to the operator. The path of the railway track is indicated on a geographical map projection and includes surrounding land. In this example the railway track is displayed as a colour or grey scale or cross-hatching containing regions of probabilities of there being a fault at that geographic location.

Referring to FIG 12. There is shown a schematic of a data acquisition and recording apparatus which is mounted on a moving vehicle **V**. The apparatus comprises of a plurality of acoustic transducers. In the example shown in FIG 12, transducer **T1** functions as a transmitter and the transducers **R1, R2, R3** and **R4** function as receivers. Additional receivers and transmitters may be included, or the location of the transmit transducer relative to the receiver transducers may be adjusted together with the distance between them to meet particular survey requirements. As the vehicle moves along the railway track a sound pulse or predetermined waveform is transmitted by transducer **T1**. The sound wave propagates within and along the surface of the rail. The wave is detected a various points along the rail by receiver transducers **R1** to **R4**. Or to as many additional receivers that may be required.

Referring to FIG 13. There is shown a schematic of the data acquisition and recording apparatus as detailed in FIG 12, with transducers **T1, R1** to **R4** but which has in

addition transducers measuring other physical properties of the rail. All these transducers being mounted on a vehicle **V** to form an integrated survey system.

The transducer **W** being a position sensor fitted to the vehicle wheel. This is used to detect the number of revolutions and direction of the wheel as the vehicle moves along the rail, thereby determining the vehicle and sensors position at any point along the rail.

The transducer **G** being a two axis linear distance measuring probe. This is used to measure the rails geometry, in the horizontal and vertical planes to the direction of travel. Changes in rail geometry will be apparent in cases of uneven ware of the rail, horizontal split head, shelling or detail fracture faults.

The transducer **A** being a three axis accelerometer. This is used to measure the vehicle accelerations in the x, y and z planes. Vertical accelerations giving an indication of serious rail defects such as a horizontal split heads, or at rail section changes. Horizontal accelerations giving an indication of track misalignment or at point track changes.

The transducer **H** being an induction sensor. This is used to measure the magnetic properties of the steel rail. Changes in the magnetic properties give an indication of serious external and internal defects such as vertical split heads and cracking.

If the apparatus is to be used as an independent survey vehicle the data from all these sensors is recorded and stored in a unit located on the vehicle shown at **S**.

If the apparatus is to be included within a passenger or freight train, the data from all these sensors is recorded and stored either at S or is transferred and stored at other locations within the passenger or freight train.

If the apparatus is to be towed by a rail inspection vehicle the data can be transferred to the inspection vehicle for recording, analysis and display.

Referring to FIG 14. There is shown an example of a method (option 1) by which the data is acquired. This method uses a distributed microprocessor (or transputer) arrangement and consists of microprocessors **I1, I2, I3 .... In** where n is the number of microprocessors required. The microprocessors are connected together as a linear array and each can communicated with adjacent microprocessors.

The data is acquired from each transducer concurrently (in parallel). The transmit transducer also sends a signal concurrently during the sampling period.

During the sampling process the received signals from each of the sensors **R1, R2, R3..... Rn** is first amplified by pre-amplifiers **PR1, PR2.... PRn** then digitised using its respective Analogue to Digital converters **AD1, AD2.....ADn** . This digital data is then stored in its respective memories **DM1, DM2.....DMn**. When the sample is complete the data is then transferred to its respective microprocessor **I1, I2....In** under the control of interface circuitry **IC1, IC2....ICn**. The memory **M1, M2....Mn** serves as a temporary data store and program store for the microprocessors.

The data is then pipelined through the linear array of microprocessors to the recording, processing, analysis and display facility. Some processing of the data may be carried out during this pipeline transferring process.

Prior to the sampling process the required transmit signal waveform is loaded in to the digital memory **DM0** of the transmitter section by the microprocessor **I0** via the interface circuitry **IC0**. When sampling takes place this digital waveform data is

clocked into the Digital to Analogue converter **DA0**, the resulting analogue signal is amplified by the power amplifier **PA0** and sent to the transmit transducer **T1**.

If the apparatus were to be used in transmitting a pulse only then **DM0** and **DA0** can be omitted. The power amplifier **PA0** being driven from a signal pulse derived from the microprocessor **I0** via suitable circuitry.

The allocation of the sensors **R1, R2....Rn** will depend upon the survey requirements. For example **R1** to **R8** may be allocated to ultrasonic transducers, **R9** to **R11** accelerometers, **R12** and **R13** to rail geometry sensors, **R14** to position sensor and **R15** to induction sensor.

Referring to FIG 15. There is shown an example of a method (option 2) by which the data is acquired. This method uses a single microprocessor **IM**. That has associated with it memory **MM**. This memory serves as a temporary data store and program store for the microprocessor.

In addition to this memory and residing in the microprocessors memory address space are memory elements **M0, M1, M2...Mn** where n is the number of sensor channels required.

During the sampling process the received signals from each of the sensors **R1, R2....Rn** is first amplified by its respective pre amplifiers **PR1, PR2.....PRn** then digitised using its respective Analogue to Digital converters **AD1, AD2....ADn**. This digital data is then stored in memory elements **M1, M2...Mn**. These memory elements are connected within the microprocessor **IM** memory space. When the sampling is complete the data is processed by the microprocessor for recording analysis and display.

Prior to the sampling process the required transmit signal waveform is loaded in to the digital memory of the transmitter memory section **M0**. When sampling takes place this digital waveform data is clocked into the Digital to Analogue converter **DA0**, the resulting analogue signal is amplified by power amplifier **PA0** and sent to the transmit transducer **T1**.

If the apparatus were to be used in transmitting a pulse only then **M0** and **DA0** can be omitted. The power amplifier **PA0** being driven from a signal pulse derived from the microprocessor **IM** via suitable circuitry.

The allocation of the sensors **R1, R2....Rn** will depend upon the survey requirements. For example **R1** to **R8** may be allocated to ultrasonic transducers, **R9** to **R11** accelerometers, **R12** and **R13** to rail geometry sensors, **R14** to position sensor and **R15** to induction sensor.

Referring to FIG 16, there is shown an example of the method by which the apparatus performs data processing and analysis. The principle involves the measurement of

changes in the spectral components of a surface wave travelling along the railhead, with the other sensors used to determine the integrity of the data.

The sensors, S1, S2, S3, S4 and **S5** are used to measure the transmitted ultrasonic waves, the rail geometry, the accelerations of the vehicle , the induction properties of the rail's steel track and the position of the vehicle respectively.

The rail geometry measurements are recorded to monitor rail wear and detect rail defects. The accelerometers are used to detect serious rail problems such as horizontal split heads, and can be used to detect the point at which the rail sections change. Induction measurements complement the ultrasonic data in fault detection and diagnosis.

The positional sensors provide details of track fault locations. Rolling wheel counters are used to determine location. GPS can be used to give additional accuracy to the positional data.

The filter, F is applied to the ultrasonic data to remove any unwanted low frequency rumble or high frequency noise generated as the trolley moves over the track.

The exceptional situation detector, E is used to take account of rail section changes or welds. Sensor information from rail geometry, accelerometers and the induction sensors are used to detect for abnormalities. For example at a rail section change the accelerometers will indicate a large sudden change in the vertical direction. At points there will be horizontal accelerations. In the presence of split heads there will be rapid changes in the rail geometry. At welds the induction sensors will show a change. Exceptional situations may also arise from the acquired ultrasonic data, the signal level may fall below a pre-determined value, indicating a large attenuation in the sound transmission. The time period between transmission and reception of the sound wave may also fall outside expected values (velocity variation).

The separate or combined information from all these sensors is used to determine if an exception has occurred. This is logged together with its position and details about the exception.

The fast fourier transform FFT, this converts the ultrasonic data in the form of amplitude verses time to a frequency spectra (amplitude verses frequency component).

The spectral comparison SPC, this compares the spectrum of the acquired ultrasonic data spectrum to that of the spectrum that would be expected from a good sample of rail. The difference between the two is a measure of the degree of defects that exist at the time of sampling.

The probability of failure computation POF, this determines the degree of probability that there is a fault at a specific location. A wide range of known software techniques can be employed in this evaluation and can include Neural Network methods.

Data display DD, this uses various methods to display the data. From coloured or shaded maps to data print outs. Displays may also be required of data from a single sensor, for example the induction values separately from that of the ultrasonic data.

The record section REC1 provides a permanent recording of the raw data from all the sensors and transducers. This is used should further post processing of the data be required. This data is stored continuously throughout the data acquisition process.

The record section REC2 provides a permanent record of the exceptions log. This data is stored continuously throughout the data acquisition process. It would include details of the exception.

The record section REC3 provides a permanent record of the processed data as observed by the operator when the apparatus is used for real time data analysis.

An example of an efficient method for recording the data is optical disk storage, or magnetic disk storage.

Referring to FIG 17, there is shown an example of a method by which the apparatus can perform the evaluation of the surface wave velocity.

Data from a plurality of ultrasonic transducers **S1, S2...Sn** where n represents the total number of transducers, is sent to their respective first break detectors **FB1, FB2....FBn** here an algorithm is used to determine the time at which the required wave reaches the transducer. The time values for each of the transducers are then sent to the time difference evaluator **TDE** where the time difference between transducers is calculated, these time differences are sent to the average surface wave velocity evaluator **AVSWV** this data is then used with the exceptional situation detector detailed in FIG 16 to determine if a fault is present at a specific location.

SUMMARY

The data recording apparatus and method which has been described is a portable apparatus able to carry out data acquisition and analysis to determine the location of a variety of faults that occur on railway tracks.

The apparatus is capable of data acquisition and processing under the control of software programming. The data from sensors employed in the apparatus may be displayed for independent assessment of the condition of the rail or for quality control. The final results may be produced in real time while the survey is taking place or at a later date if post processing is required.

I claim:

1. A method for non-destructively testing materials to determine the presence of defects, comprising the steps of:-

a) Transmitting a surface acoustic wave over the material using a first transducer.

b) Receiving signals of said surface acoustic wave using a second transducer, or a plurality of transducers, positioned at a known distance from the first transducer and along the path of propagation of the surface acoustic wave.

c) Comparing the time delay, amplitude and frequency content of the received signals to determine anomalies indicative of structural defects.

2. A method according to claim 1 wherein the step of transmitting a surface acoustic wave comprises an impulse.

3. A method or apparatus according to claim 1 wherein the step of transmitting a surface acoustic wave comprises a frequency sweep.

4. A method or apparatus according to claim 1 wherein the step of transmitting a surface acoustic wave comprises applying a fixed frequency of known duration.

5. A method or apparatus according to claim 1 wherein the step of transmitting a surface acoustic wave comprises applying a mechanical load to the material's surface.

6. A method or apparatus according to claim 1 wherein the step of transmitting a surface acoustic wave comprises applying an intense focused laser beam pulse to the material's surface.

7. A method or apparatus according to claim 1 wherein the step of transmitting a surface acoustic wave comprises an induced electric current in the presence of a magnetic field, known as an Electro-Magnetic Acoustic transducer (EMAT).

8. A method or apparatus according to claim 1 wherein the step of transmitting a surface acoustic wave comprises a piezoelectric transducer in contact with the material's surface.

9. A method or apparatus according to claim 1 wherein the step of receiving acoustic wave signals from the material comprises a piezoelectric transducer in contact with the material's surface.

10. A method or apparatus according to claim 1 wherein the step of receiving acoustic wave signals from the material's surface comprises an induced electric current in the presence of a magnetic field, known as an Electro-Magnetic Acoustic transducer (EMAT).

11 A method or apparatus according to claim 1 wherein the step of receiving acoustic wave signals from the material's surface comprises an optical interferometer.

12 A method or apparatus according to claim 1 wherein the step of receiving acoustic wave signals from the material's surface comprises an air coupled acoustic transducer.

13 A method or apparatus according to any of claims 1 to 12 wherein testing or monitoring the integrity of the material comprises detecting the presence or absence of at least one or more of the following defects.

a) cracks in the material.
b) breaks in the material.
c) de-lamination of the material.
d) changes in the material's geometry.

14, An apparatus or method for non-destructively and continuously testing railway track rails, as claimed in claims 1 to 13, further comprising:

(a) A means for progressing the acoustic equipment along the rail (**V** Fig12).

(b) A means of transmitting a surface acoustic wave, over the rail's surface. Using a transducer (**T1** Fig12)

(c) A means of receiving signals of said surface wave using a second transducer, or a plurality of transducers. (**R1, R2, R3, R4** Fig12).

(d) A means to measure and compare the time delay for the surface wave to travel from the transmitter (**T1** Fig12) to one or more of the receivers (**R1, R2, R3, R4** Fig12) over a known distance (Fig 9 and Fig 17).

(e) A means to compare the magnitude of the received surface wave signals from the receivers (**R1, R2, R3, R4** Fig12 and Fig 9).

(f) A means to compare the frequency spectra of the received surface wave signals from the receivers (**R1, R2, R3, R4** Fig12 and Fig 4).

15 An apparatus for non-destructively and continuously testing railway track rails, as claimed in claims 1 to 14, further comprising:

(a) A means for amplifying the said surface wave signals (**PR1, PR2, PRn** Fig 14 and Fig 15)

(b) A means for converting analogue signals to digital form (**AD1, AD2, ADn** Fig 14 and Fig 15)

(f) A means for performing digital signal processing and computation, comprising of one or a plurality of microprocessors (**M0, M1, M2, Mn** Fig 14 and **IM** Fig 15).

(g) A means for storing data in a memory (**M0, M1, M2, Mn** Fig 14 and **MM** Fig 15).

16 An apparatus for non-destructively and continuously testing railway track rails, as claimed in claims 1 to 15, further comprising:

(a) A means to detect changes in rail geometry (**G** Fig13),

(b) A means to detect accelerations in one or more directions (**A** Fig13)

(c) A means to detect the inductive field surrounding the rail (**H** Fig13).

(d) A means to determine the position of the apparatus along the rail **W** (Fig13),

(e) A means to record and store data (**S** Fig13).

(f) A means to determine exceptional situations in the recorded data values (**E** Fig 16).

(g) A means to determine the probability of rail defect or failure (**POF** Fig 16)

(h) A means of displaying data as a map superimposed with the probabilities of faults along the path of the railway track (Fig 11).

Amendments to the claims have been filed as follows

I claim:

1. A method for continuously and non-destructively testing railway track rails to determine the presence of defects, comprising the steps of:-

a) Transmitting a surface acoustic wave over the rail's surface using a first transducer.

b) Receiving signals of said surface acoustic wave using a second transducer, or a plurality of transducers, positioned at a known distance from the first transducer and along the path of propagation of the surface acoustic wave.

c) Combining and comparing the measurements of time delay, amplitude and frequency content of the received acoustic signals, together with measurements of rail geometries, rail displacements and rail electro-magnet induction to determine anomalies indicative of rail defects.

d) Determining the probability of there being a rail defect at a specific location.

2. A method according to claim 1 wherein the step of transmitting a surface acoustic wave comprises an impulse.

3. A method or apparatus according to claim 1 wherein the step of transmitting a surface acoustic wave comprises a frequency sweep.

4. A method or apparatus according to claim 1 wherein the step of transmitting a surface acoustic wave comprises applying a fixed frequency of known duration.

5. A method or apparatus according to claim 1 wherein the step of transmitting a surface acoustic wave comprises applying an intermittent mechanical load to the rail's surface.

6. A method or apparatus according to claim 1 wherein the step of transmitting a surface acoustic wave comprises applying an intense focused laser beam pulse to the rail's surface.

7. A method or apparatus according to claim 1 wherein the step of transmitting a surface acoustic wave comprises an induced electric current in the presence of a magnetic field, known as an Electro-Magnetic Acoustic transducer (EMAT).

8. A method or apparatus according to claim 1 wherein the step of transmitting a surface acoustic wave comprises a piezoelectric transducer in rolling or sliding contact with the rail's surface.

9. A method or apparatus according to claim 1 wherein the step of receiving acoustic wave signals from the rail comprises a piezoelectric transducer in rolling or sliding contact with the rail's surface.

10. A method or apparatus according to claim 1 wherein the step of receiving acoustic wave signals from the rail's surface comprises an induced electric current in the presence of a magnetic field, known as an Electro-Magnetic Acoustic transducer (EMAT).

11 A method or apparatus according to claim 1 wherein the step of receiving acoustic wave signals from the rail's surface comprises an optical interferometer.

12 A method or apparatus according to claim 1 wherein the step of receiving acoustic wave signals from the rail's surface comprises an air coupled acoustic transducer.

13 A method or apparatus according to any of claims 1 to 12 wherein testing or monitoring the integrity of the rail comprises detecting the presence or absence of at least one or more of the following rail defects.

a) cracks in the rail.
b) breaks in the rail.
c) de-lamination of the rail.
d) changes in the rail's geometry.

14, An apparatus or method for non-destructively and continuously testing railway track rails, as claimed in claims 1 to 13, further comprising:

(a) A means for progressing the acoustic equipment along the rail (V Fig12).

(b) A means of transmitting a surface acoustic wave, over the rail's surface. Using a transducer (T1 Fig12)

(c) A means of receiving signals of said surface wave using a second transducer, or a plurality of transducers. (R1, R2, R3, R4 Fig12).

(d) A means to measure and compare the time delay for the surface wave to travel from the transmitter (T1 Fig12) to one or more of the receivers (R1, R2, R3, R4 Fig12) over a known distance (Fig 9 and Fig 17).

(e) A means to compare the magnitude of the received surface wave signals from the receivers (R1, R2, R3, R4 Fig12 and Fig 9).

(f) A means to compare the frequency spectra of the received surface wave signals from the receivers (R1, R2, R3, R4 Fig12 and Fig 4).

15 An apparatus for non-destructively and continuously testing railway track rails, as claimed in claims 1 to 14, further comprising:

(a) A means for amplifying the said surface wave signals (PR1, PR2, PRn Fig 14 and Fig 15)

(b) A means for converting analogue signals to digital form (AD1, AD2, ADn Fig 14 and Fig 15)

(f) A means for performing digital signal processing and computation, comprising of one or a plurality of microprocessors (**M0, M1, M2, Mn** Fig 14 and **IM** Fig 15).

(g) A means for storing data in a memory (**M0, M1, M2, Mn** Fig 14 and **MM** Fig 15).

16 An apparatus for non-destructively and continuously testing railway track rails, as claimed in claims 1 to 15, further comprising:

(a) A means to detect changes in rail geometry (**G** Fig13),

(b) A means to detect accelerations in one or more directions (**A** Fig13)

(c) A means to detect the inductive field surrounding the rail (**H** Fig13).

(d) A means to determine the position of the apparatus along the rail **W** (Fig13),

(e) A means to record and store data (**S** Fig13).

(f) A means to determine exceptional situations in the recorded data values (**E** Fig 16).

(g) A means to determine the probability of rail defect or failure (**POF** Fig 16)

(h) A means of displaying data as a map superimposed with the probabilities of faults along the path of the railway track (Fig 11).

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Application No: GB 0130609.1 **Examiner:** Peter Easterfield
Claims searched: 1 to 16 **Date of search:** 7 April 2003

Patents Act 1977 : Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance	
X	1,13 at least	US 5426979 A	(KANTOROVICH et al)
X	1,13 at least	US 4307614 A	(TITTMANN et al)
X	1,13 at least	US 4274288 A	(TITTMANN et al)
X	1,13 at least	US 5035143 A	(LATIMER et al)
X	1,13 at least	US 5894092 A	(LINDGREN et al)
X	1,13 at least	GB 1551994 A	(CENTRE TECHNIQUES)
A		GB 2371623 A	(GUIDED ULTRASONICS)

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&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC[V]:

G1G

Worldwide search of patent documents classified in the following areas of the IPC[7]:

B61K; G01N

The following online and other databases have been used in the preparation of this search report:

WPI, EPODOC, JAPIO

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